Parameterization of inclusive double differential cross section for secondary particle production in the atmosphere.

L. Derome, M. Buénerd

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Parameterization of inclusive double differential cross section for secondary particle production in the atmosphere.

L. Derome[a], M. Buénerd[a]

(a) Laboratoire de Physique Subatomique et de Cosmologie, 53, avenue des Martyrs - Grenoble, France

Presenter: L. Derome (laurent.derome@lpsc.in2p3.fr), fra-derome-L-abs2-he21-poster

The precise knowledge of the production cross section for secondary particles is a fundamental input to a large class of calculations like atmospheric secondary particle flux or neutrino beam flux from accelerators. Standard calculations usually employ nuclear model based (Monte-Carlo generator) codes to derive these cross sections. In this contribution an alternative tool is presented consisting of a set of parameterizations based on simple phenomenological formulas fitted to a large set of experimental data. The following inclusive reactions are included : A + B → C + X where A is the incident particle (proton, neutron, Helium) with energy up to several tens of GeV, B is the target (nuclei between Helium and Copper) and C is the produced particle whose production cross section is parametrized : proton, neutron, antiproton, pion, kaon, and light nuclei (deuteron to helium, from low energy coalescence production). This tool has the great advantage of simplicity and adaptability. It will be easily updated to incorporate the new sets of data from recent nuclear experiment like HARP and MIPP.

1. Introduction

The differential cross section computation tool presented in this contribution, includes a set of parametrization formulas based on the Kalinovsky-Mokhov-Nikitin (KMN) parametrization of the inclusive cross sections [1]. The accumulation of data over the past three decades makes it necessary to revisit the original KMN type of parametrizations by fitting them to the new data.

2. Proton Production

The invariant proton and neutron production cross sections in pA and nA collisions were described by means of the parametrization adapted from [1] where a phenomenological formula was constructed, based on prediction of the Regge Model. The main improvements introduced here are a proper treatment of the quasi-elastic production, by explicitly taking into account the different resonances [3] to replace the "leading" term in [1], and the inclusion of the deep-inelastic component to account for the very low energy and backward proton production. The latter was included using the parametrization proposed in [2].

The cross section has been fitted over a large set of data (see table 1). An example of the parametrization obtained is shown on figure 1.left with the comparison between the data from [2] ($p + Be \rightarrow p + X$ at 7.5 Gev/c) and the fit results, the gray area corresponds to the 95% confidence interval. The kinematics for these data is illustrated on figure 1.right where the data (open squares) are plotted in the rapidity-transverse momentum plane. In the kinematic region covered by these data (low energy and large production angle of the particle) the invariant cross section is dominated by the deep-inelastic component. As an other example, figure 2 shows the comparison of the data from [5] with the fit results. These data correspond to the forward region of the production kinematics (see figure 2.right) where the component from KMN [1] is dominant.

Table 1. Sets of experimental data used to fit the proton production cross sections. N_{dat} are the number of data points in the corresponding set.

auth [Ref.]	P_{in} (GeV/c)	Target	θ_{lab} range (deg)	p (GeV/c)	N_{dat}
Shibata et al. [6]	1.4,2.5,4	C, Cu	30-120	0.3-0.5	220
Agakishiev et al. [7]	4.2	C	5-80	0.5 - 5.0	85
Bayukov et al. [2]	7.5	C	10-160	0.4 - 0.7	115
Dekkers et al. [4]	11.8,18.8,23.1	Be	0-5	4-12	27
Abbot et al. [11]	14.6	Be	7 -50	1-6	233
Allaby et al. [5]	19.2	Be,Cu	0.5-4	6-18	110
Bayukov et al. [8]	400	Be,C,Cu	70 - 120	0.4 -1.	95

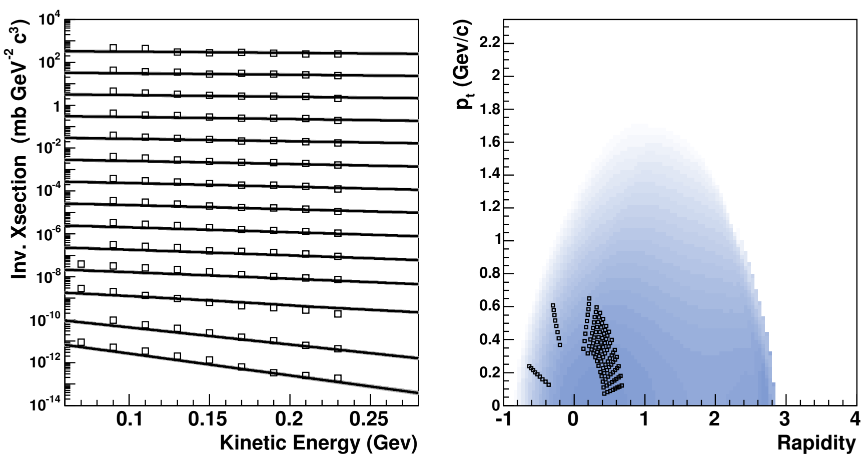

Figure 1. Left : Proton invariant cross section $E\frac{d^3\sigma}{d^3p}$ measured (open square) in the reaction $p+Be \rightarrow p+X$ at 7.5 Gev/c [2] compared the fitted parametrization as a function of the proton kinetic energy and for different production angles in the laboratory : 10^o, 15^o (scaled by a factor 10^{-1}), 20^o ($\times 10^{-2}$), 25^o ($\times 10^{-3}$), 29^o ($\times 10^{-4}$), 35^o ($\times 10^{-5}$), 40^o ($\times 10^{-6}$), 44^o ($\times 10^{-7}$), 49^o ($\times 10^{-8}$), 54^o ($\times 10^{-9}$), 59^o ($\times 10^{-10}$), 69^o ($\times 10^{-11}$), 119^o ($\times 10^{-12}$), 160^o ($\times 10^{-13}$). Right : kinematics of the data in the rapidity-transverse momentum plane (open square) and plot of the Invariant Cross section.

3. Pion Production

For the inclusive pion production cross sections, a formula based on the KMN parametrization of the cross sections [1] was used. The parameters of these formulas have been fitted to a wide range of $p + A \rightarrow \pi^{\pm} + X$ data between 1.38 and 400 GeV/c incident momenta (see table 2). Figure 3 shows the results of the fit compared to the data from [12]. For π^0 production cross section, the mean value of the π^+ and π^- cross section was used.

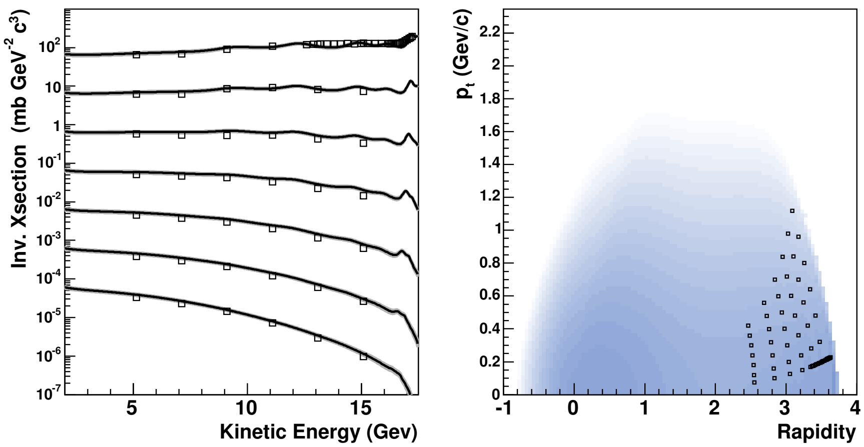

Figure 2. Left : Proton invariant cross section measured (open square) in the reaction $p + Be \rightarrow p + X$ at 19 Gev/c [5] compared with the fitted parametrization in function of the proton kinetic energy and for different production angles : 0.716^o, 1.146^o (scaled by a factor 10^{-1}), 1.719^o ($\times10^{-2}$), 2.292^o ($\times10^{-3}$), 2.865^o ($\times10^{-4}$), 3.438^o ($\times10^{-5}$) , 4.011^o ($\times10^{-6}$). Right : Same as in figure 1 for the above data.

Table 2. Sets of experimental data used in the study for pion production.

	P_{in}	Target	θ_{lab} range	π^+		π^-	
auth [Ref.]	(GeV/c)		(deg)	p (GeV/c)	N_{dat}	p (GeV/c)	N_{dat}
Cochran et al. [9]	1.38	C	$15 - 150$	$0.1 - 0.7$	107	$0.1 - 0.7$	92
Cho et al. [10]	12.4	Be	$0.1 - 12$	$2. - 6.5$	54	$2. - 6.5$	33
Abbot et al. [11]	14.6	Be, Al	$7 - 55$	$0.7 - 4.5$	186	$0.7 - 4.5$	181
Eichten et al. [12]	24	Be, Al	$1 - 7$	$4 - 18$	132	$4 - 18$	106
Pap et al. [13]	1.75,2.5,5	Be, C	2.5	$0.5 - 3.5$	40	$0.5 - 4$	48
Voron et al. [14]	10.1	Be, Al	3.5	$1. - 4.5$	28	$1 - 5$	26
Abramov et al. [15]	70	C, Al	9.	$6. - 30$	15	$6. - 30$	15
Antreasyan et al. [16]	200,300,400	Be	4.5	$10 - 60$	9	$10 - 60$	9

4. C++ implementation of the Cross-Section parametrization

The above parametrizations are available from the authors as a C++ library (see [17]). This library can be used to compute any of the cross sections for the reactions :

$$\begin{pmatrix} p, n \\ \text{He}\ldots \end{pmatrix} + A \rightarrow \begin{pmatrix} p, n \\ \text{D,T,}^3\text{He,}^4\text{He} \\ \pi^{\pm,0} \\ K^{\pm,0} \end{pmatrix}$$

by means of the parametrizations presented in the previous sections. For light nuclei production D,T,^{3}He,^{4}He the coalescence model is used (see [18] for more details). For the Kaon production, the parametrization from

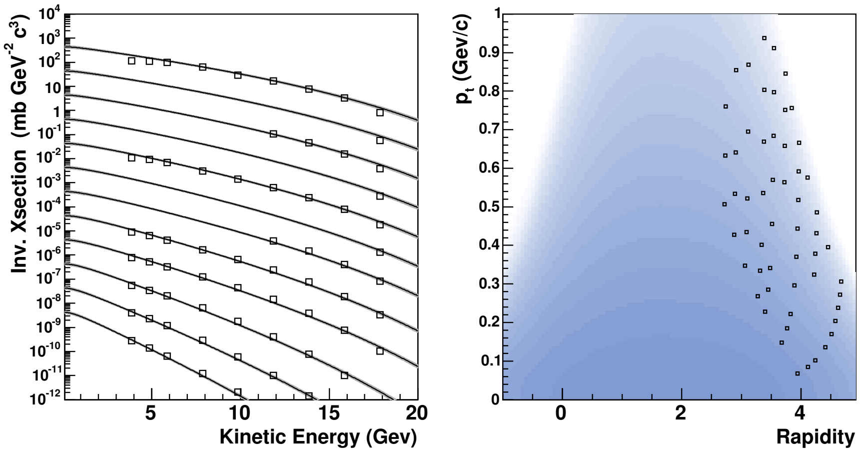

Figure 3. Left : π^+ Cross section measured (open square) in the reaction $p+Be \to p+X$ at 24 Gev/c [12] compared with the fitted parametrization as a function of the proton kinetic energy and for different production angles : 0.974^o, 1.261^o (scaled by a factor 10^{-1}), 1.547^o ($\times10^{-2}$), 1.833^o ($\times10^{-3}$), 2.120^o ($\times10^{-4}$), 2.406^o ($\times10^{-5}$), 2.693 ($\times10^{-6}$), 3.266 ($\times10^{-7}$), 3.839 ($\times10^{-8}$), 4.985 ($\times10^{-9}$), 6.131 ($\times10^{-10}$), 7.277 ($\times10^{-11}$). Right: Same as in figure 1 for these data.

[1] is used without any modification. For $A > 1$ incident Nuclei, the cross section is given by a functional dependence of A from of fit to the [19] data times the proton nucleus section.

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